

Stray Light Characterizations for MOBY

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2001 Ocean Color Research Team Meeting

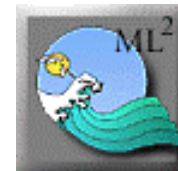
San Diego, California

May 21 to 24, 2001



NIST

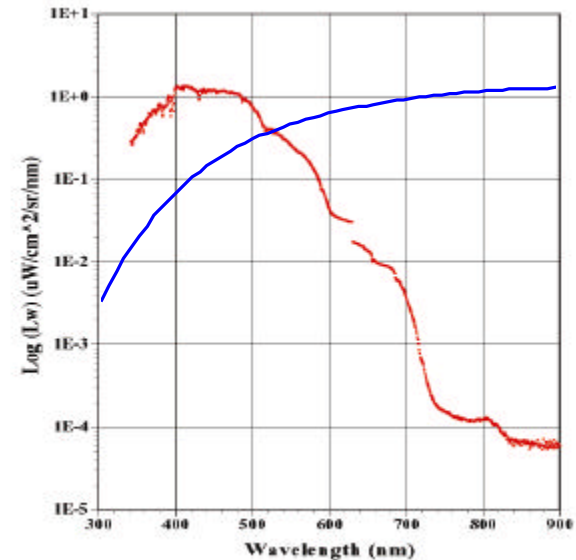
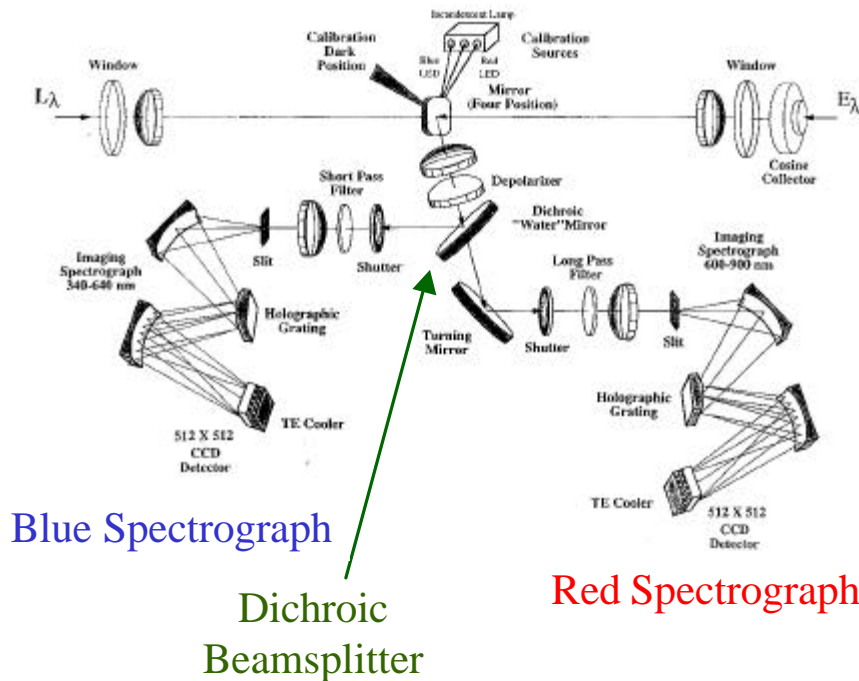
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce



Abstract. The Marine Optical Spectrographic (MOS) system is used in two configurations; one for the Marine Optical Buoy (MOBY) and as a shipboard profiler. Both systems are used for vicarious calibration of satellite ocean color sensors, e.g. MODIS, SeaWiFS, OCTS, POLDER, and IRS1-MOS. Band-averaged normalized water-leaving radiances, L_{WN} 's are reported by the MOBY team, corresponding to data sets from MOBY at the Lanai, Hawaii site and various sites for the MOS profiler. For MODIS and SeaWiFS, band-averaged L_{WN} 's are required for the range 412 nm to 670 nm. Here we report on the characterization of stray light in the MOS profiler system. For the first time, a rigorous study was possible using a broadly tunable laser facility. We report preliminary results for correction factors that are required to assess the effect of stray light on the derived up-welling radiance, based on characterizations at NIST of the MOS Profiler.

Marine Optical Spectrograph (MOS) for Marine Optical Buoy (MOBY)

MOS



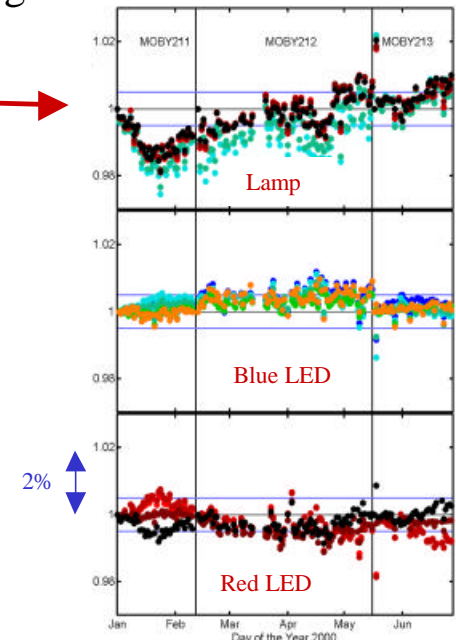
Sphere source for calibration;
Water-leaving radiance from oceans

- Radiometric Calibrations
- Wavelength Calibrations
- Temperature Effects
- Stability
- Others
- Effects of Stray Light

Uncertainty Sources

MOBY and Ocean Color

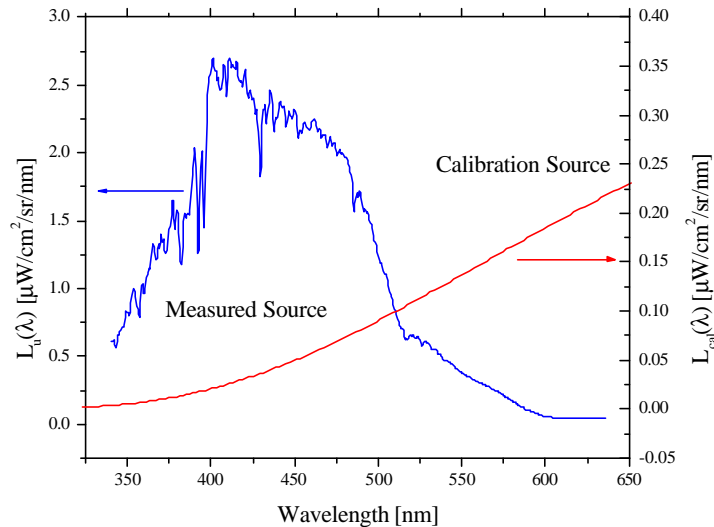
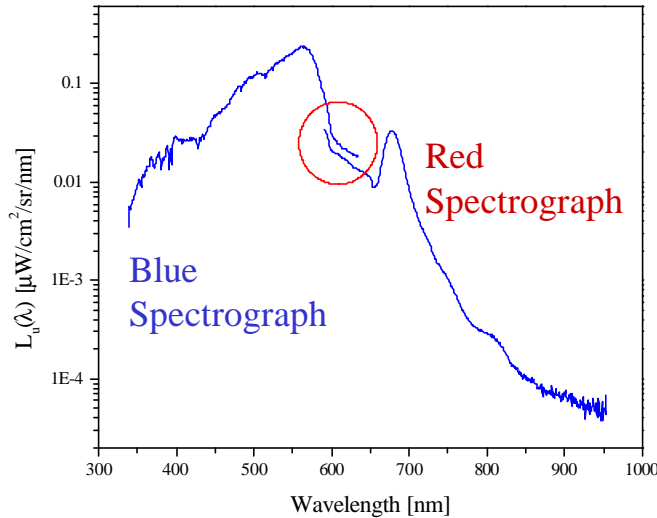
- Time series of band-averaged $L_{WN}(\lambda)$ since 1996
- Wavelength coverage from 350 nm to 950 nm
 - MOS's have dichroic beamsplitter and two single grating CCD spectrographs
- Robust radiometric traceability to NIST
 - source standards are recalibrated every 50 operating hours
 - source standards monitored using NIST-designed filter radiometers
 - annual verification by NIST/EOS calibration validation program
- Excellent stability and repeatability
 - internal calibration sources on MOBY (daily) →
 - external sources deployed by divers on MOBY (monthly)
 - all sensors calibrated pre- and post-deployment
- MOBY data sets
 - timed for MODIS and SeaWiFS overpasses (daily)
 - real time data processing
- MOS Profiler
 - during MOBY replacements (every three months)
 - dedicated cruises (MOCE's)



Venice and Monaco Presentations: <http://modis-ocean.gsfc.nasa.gov/refs.html>

R. A. Barnes et al., "The Calibration of SeaWiFS on Orbit," Proceedings of SPIE, **4135**, 281 (2000).

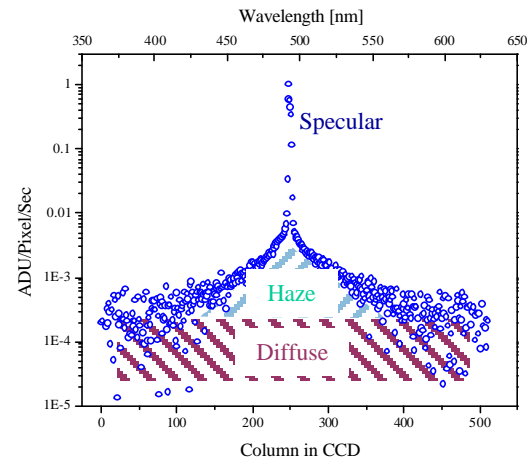
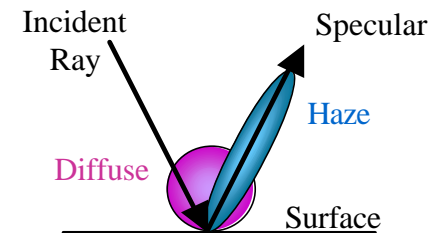
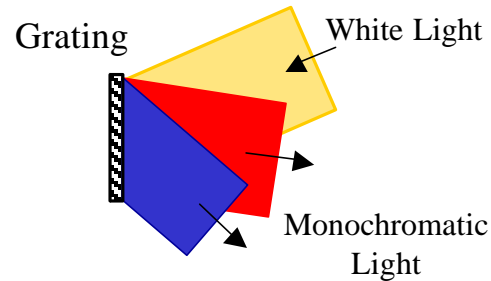
Motivation for Stray Light Work



- *Circled Region:* $L_u(I)$ derived using the two spectrographs in MOBY or the MOS Profiler disagree in their region of overlap; degree of discrepancy is depth-dependent
- But at 412 and 440 nm: $\pm 5\%$ agreement with independent filter radiometers
- “Stray light” was suspected (a typical issue with single grating spectrographs used with sources of different spectral shapes)
- NOAA and NIST addressed the problem using tools available at the time
- New facility at NIST provides rigorous solution

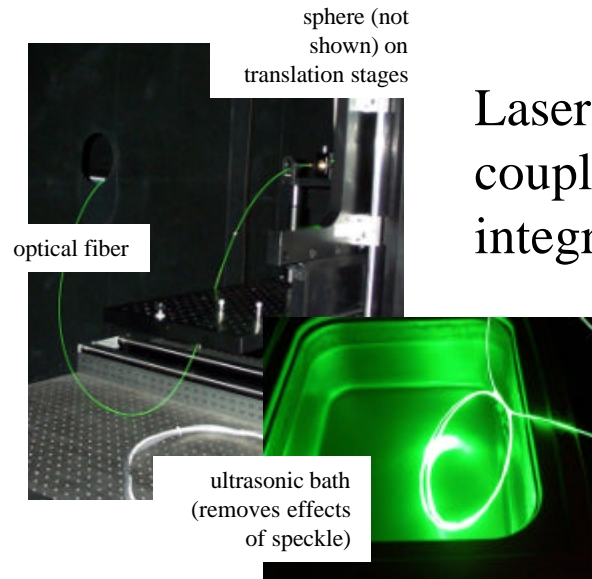
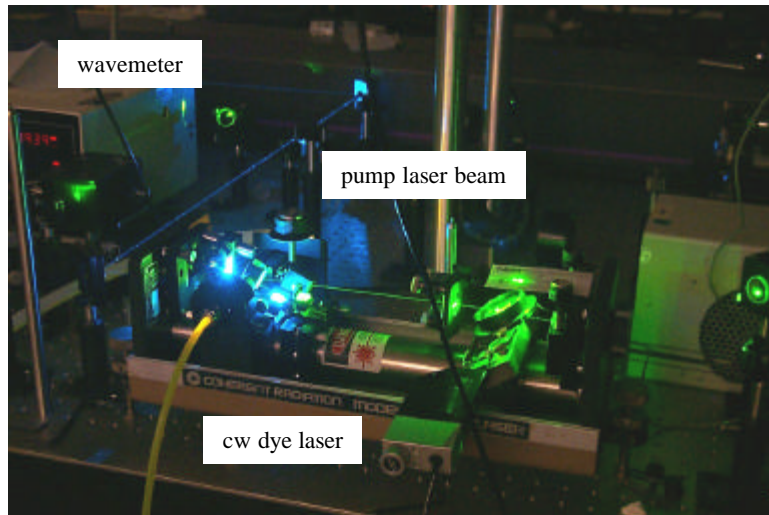
Stray Light in Spectrographs

- *Spectrograph operation*: Spectral separation by optical interference of specular reflections from grating—maps to CCD columns
- *Scattering is present*: Not all of the energy is in the specular beam, there is a forward-scattered (haze) and isotropic (diffuse) component (plus scattered light from remaining optical elements)
- “*Out of Band*”: Result is the spectral selection is not ideal (ideal would be a Delta function)
- *Filter Radiometer*: Same effect, but only one “band” per detector
- *Issue* for all single grating instruments



SIRCUS Calibration Facility

A variety of tunable lasers



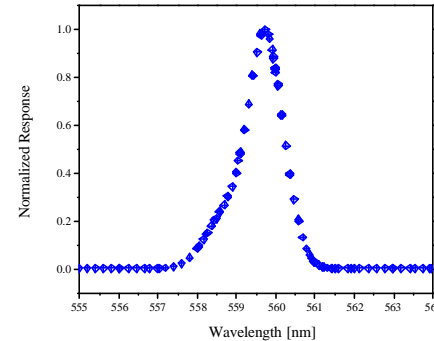
Laser output fiber-coupled into an integrating sphere

- Produces a spatially uniform, monochromatic, broadly tunable source of known radiance (0.1% uncertainty; uses transfer detectors and the NIST cryogenic radiometer)
- With $\Delta\lambda < 0.001$ nm, result is the true radiance (or irradiance) responsivity; high flux levels give excellent signal to noise ratios; optics of radiometer “filled”
- Accurate determination of “in-band” and “out-of-band” component

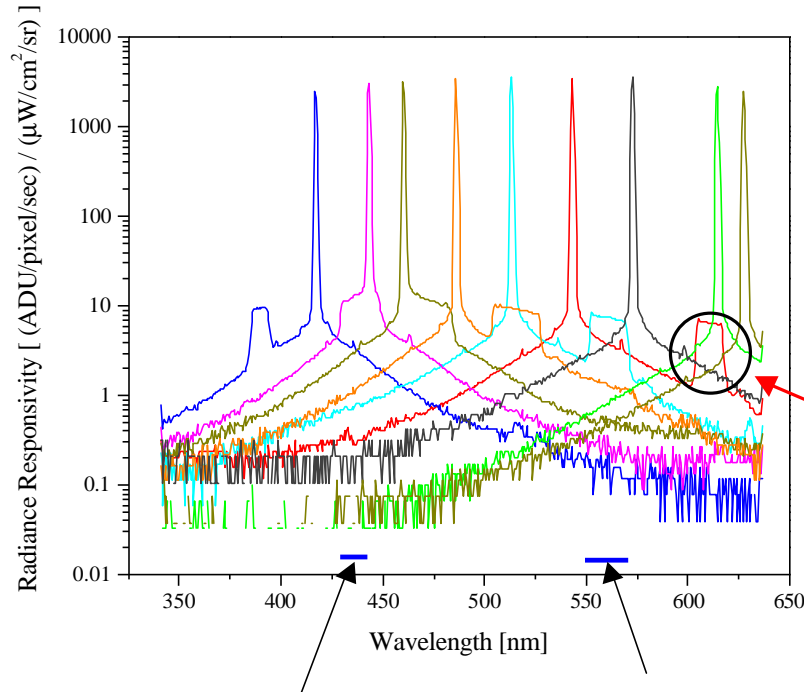
MOS Profiler—Measurements on SIRCUS

Blue Spectrograph

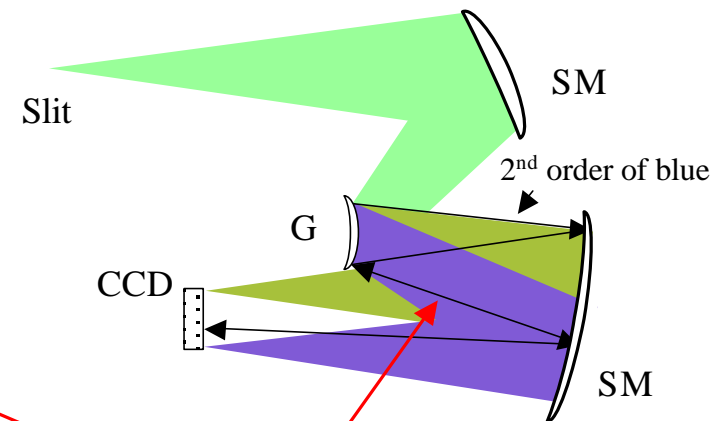
- Preliminary results
- Subset of measurements shown below (response to monochromatic flux)
- Fine scans used to get in-band shape



In-band profile gives bandwidth that is needed for correction algorithm



Two regions of fine scans (about 0.2 nm steps)

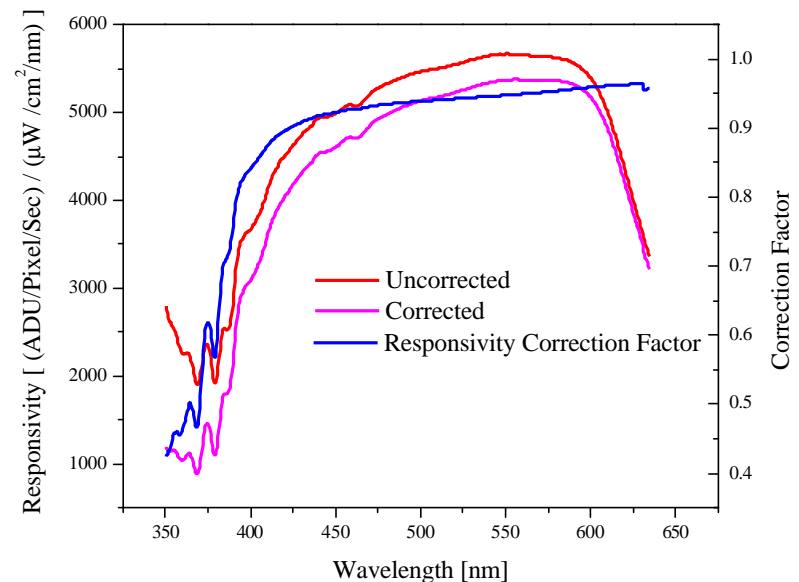


Interreflection of second order causes side lobe (MOS designed to operate in first order)

Stray Light Algorithm

$$R(\text{col}) = [S_T(\text{col}) - S_S(\text{col})]/L_{\text{cal}}(\text{col})$$

- Calibrations with broadband sphere or lamp sources give $S_T(\text{col})$, the total signal which includes effects of stray light
- $S_S(\text{col})$ depends on $L_{\text{cal}}(\text{col})$ and L_{cal} at all other wavelengths
- The algorithm finds the “true,” or “in-band” responsivity $R(\text{col})$ using a model derived from the SIRCUS characterizations
- It is a simple iterative procedure
- Algorithm validated using a colored source of known spectral radiance

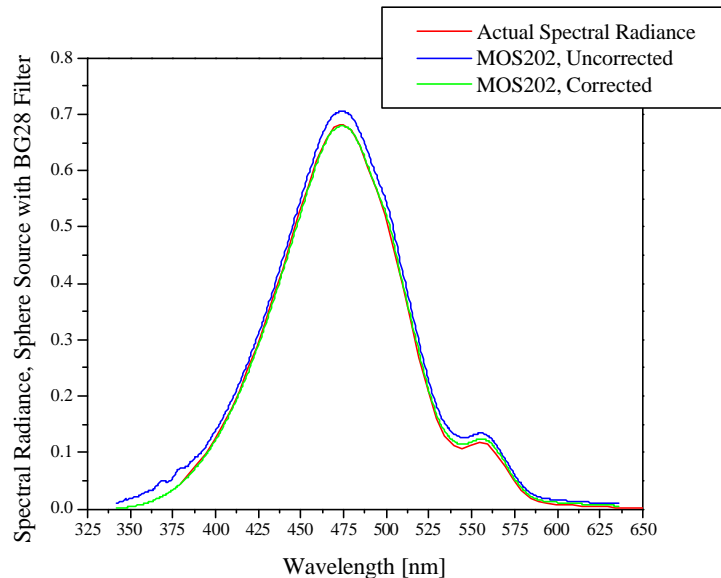


Corrected Radiances

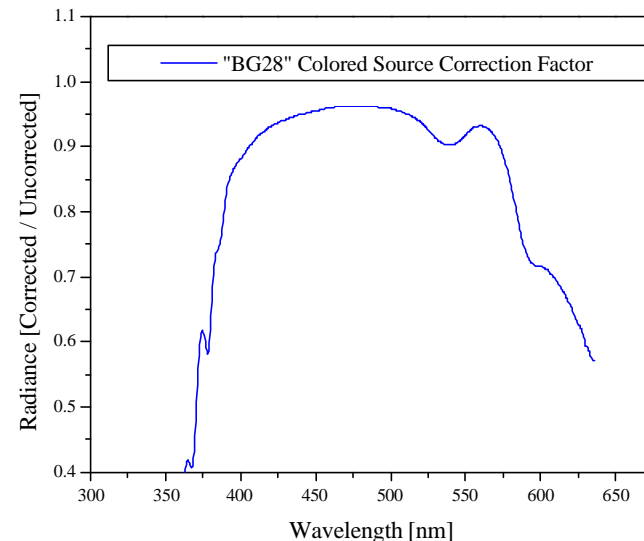
$$L_u(\lambda) = L_{cal}(\lambda) [S_T(\lambda) - S_S(\lambda)]_u / [S_T(\lambda) - S_S(\lambda)]_{cal}$$

- A second iterative procedure is used to determine the corrected water-leaving radiance from the measured count rates
- Tested using a filtered integrating sphere source

Radiances



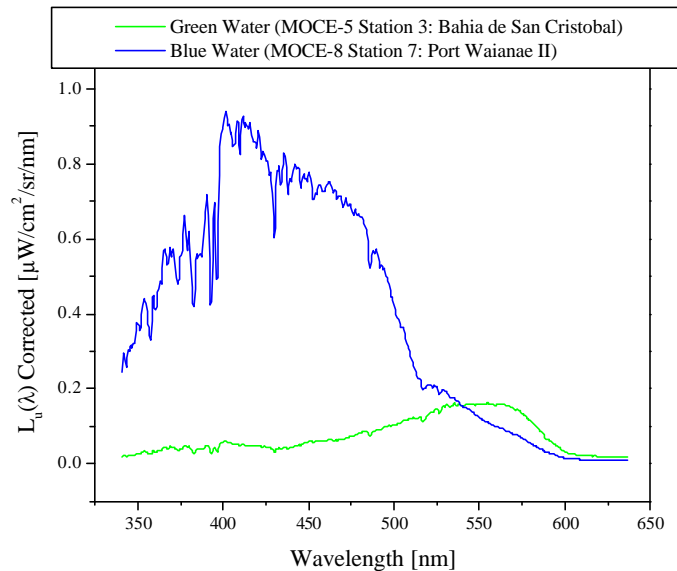
Correction Factor



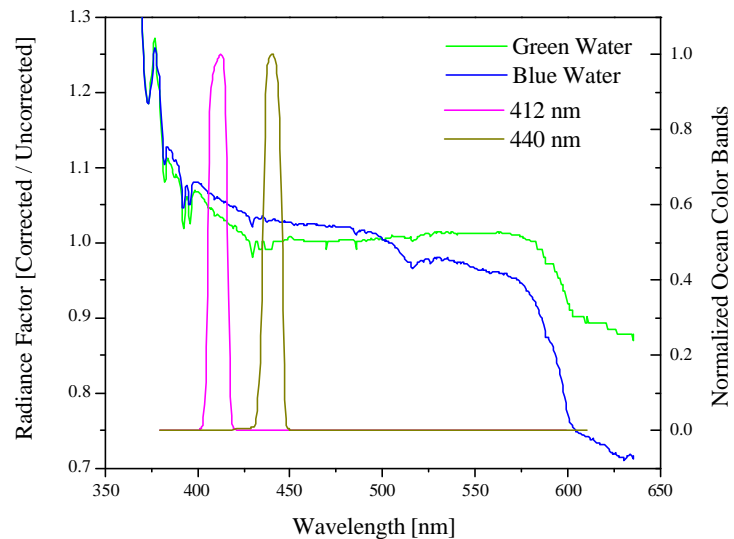
MOS Correction & MOS Data Sets

MOS 202 profiler data from representative measurements of blue and green water (October 1999 and March 2001) were corrected using the MOS SIRCUS results. The correction does not include any effects of the second order interreflections. At 412 nm, the preliminary corrections to the MOS upwelled L_u 's are between 3% and 6%.

Corrected radiances



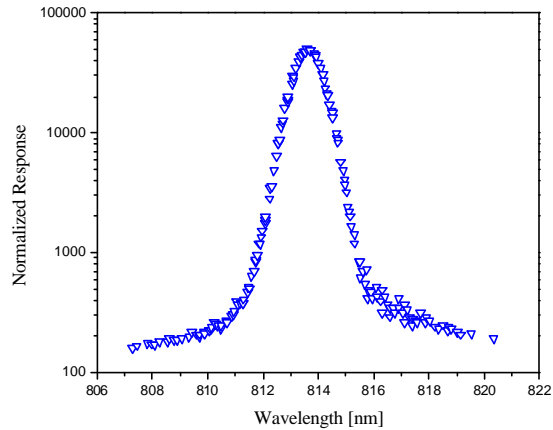
Correction factor & two ocean color bands



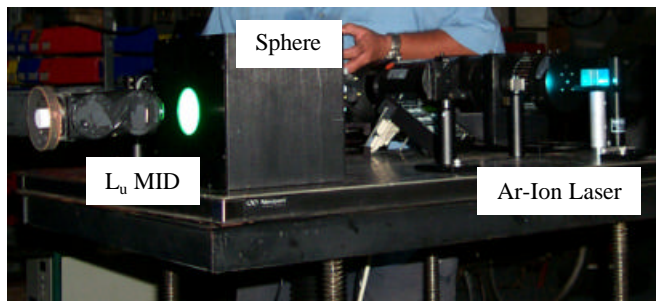
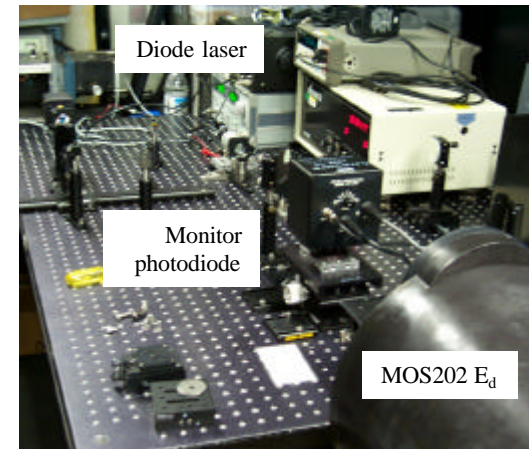
Application to MOBY

- MOBY vs. MOS Profiler on SIRCUS
 - MOBY stray light characterization **must** be done at Snug Harbor
 - Two MOS's are used on MOBY (interchanged each deployment)
 - The MOS's in MOBY are stable but “unique,” so the algorithm correction parameters will be different
 - These MOS's can be studied on MOBY, where MOS is integrated with the fiber optic inputs, or as separate optical systems
- Required Measurements
 - scans with tunable laser for bandwidth
 - measurements with fixed lasers (e.g, 412, 458, 476, 488, 514, 543, 612, and 633 nm) for out of band profile
 - adequate characterization of “2nd order reflections”
 - validation using the absolute colored sphere source
- **MOBY correction factors will be different from the MOS Profiler results presented here**

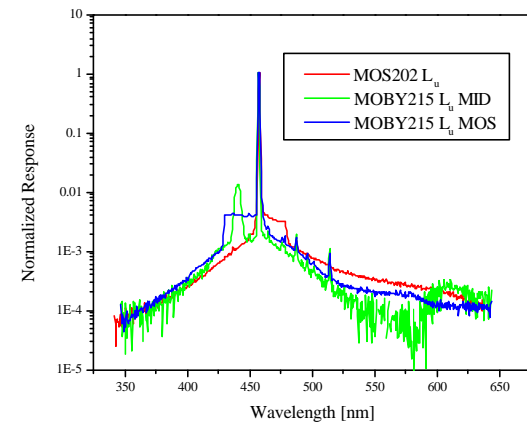
Tests to Date at Snug Harbor



Near infrared tunable diode laser used successfully with E_d and L_u port of MOS profiler



Initial tests with fixed wavelength lasers appear promising



Issues, Plans, and Summary

- Tunable “blue” laser for fine scans of blue spectrograph at Snug Harbor—issue under study
- NIST deployment in July and September 2001 to execute MOBY characterizations
- Validation of stray light correction algorithm using colored source with MOBY’s and MOS’s
- In situ validation using SIRCUS-characterized ocean filter radiometers during a MOCE cruise (winter 2001/2002)
- Fully correctable issue in instruments of proven stability will result in ocean color data set of the highest possible accuracy